Tarnishing

Gold mining may bring to mind images of grizzled prospectors prodding stubborn, overloaded burros or standing knee-deep in cold California steams, panning for nuggets. Modern gold mining, however, is a machine- and chemical-intensive endeavor in which hundreds of tons of rock are moved and processed for every ounce of gold extracted. "It's common now to talk about a one billion ton open-pit mine," says Glenn Miller, a professor of environmental and resource sciences at the University of Nevada at Reno.

According to the Worldwatch Institute, all mineral mining in Canada generates 650 million tons of waste per year. Miller estimates that each year gold mining alone in the United States generates about 1 billion tons each of waste rock and tailings (the finely ground remains of milled ore), numbers that have actually gone down in recent years, due to the drop in gold prices and the scarcity of high-grade ore.

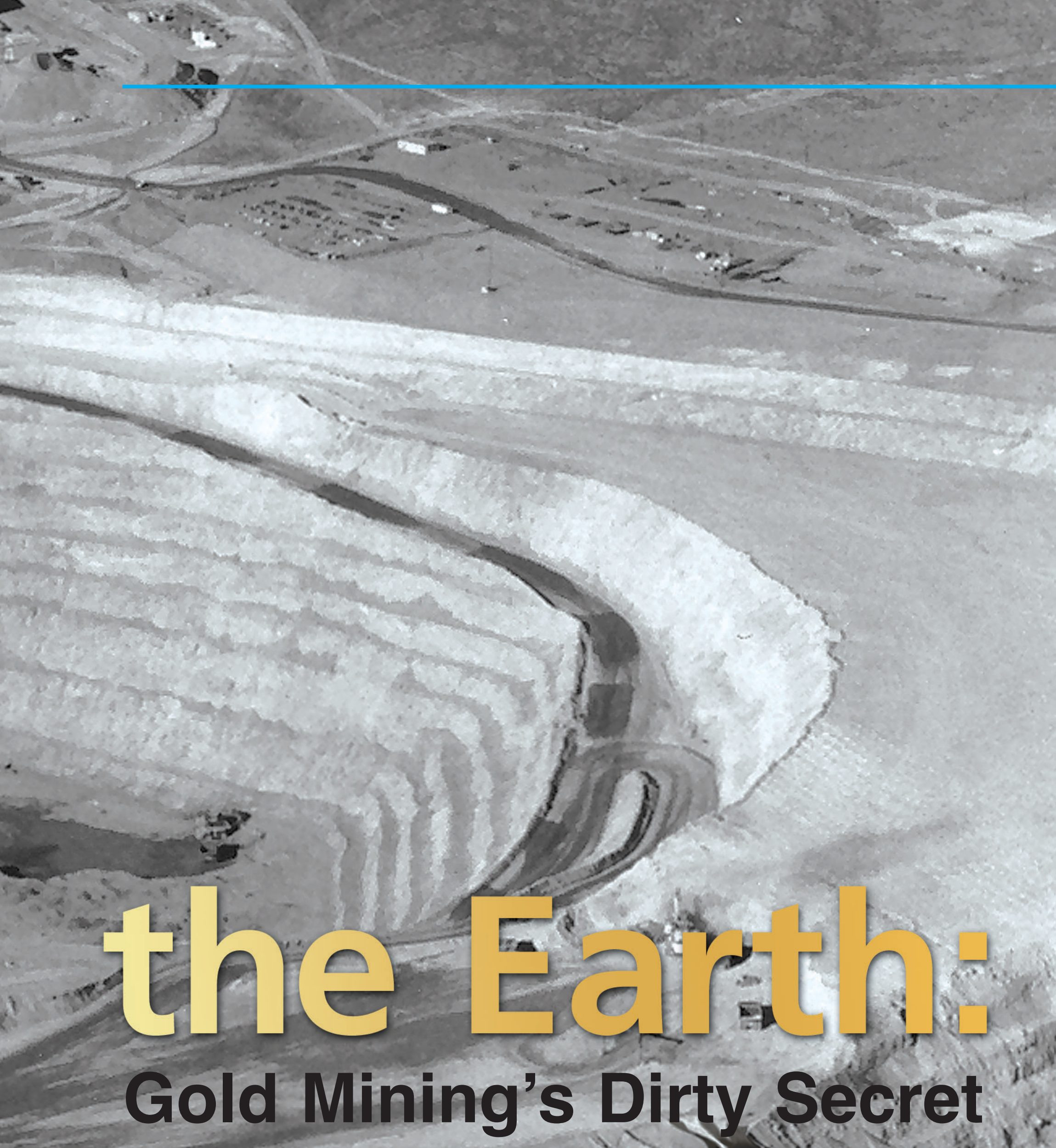
The gold nuggets and rich veins of gold of a hundred years ago are tapped out, and today's miners work deposits containing as little as 0.015 ounce of gold per ton of rock, in the process excavating as much as 4 billion tons of rock during the course of a mine's often short working life, Miller says. These massive operations bring with them new potentials for environmental damage including accelerated acidic runoff, accidental waste releases, and leachate that can infiltrate waterways and aquifers.

By no means, however, are modern megamines the only, or perhaps even primary, source of environmental damage. Long-abandoned North American gold mines and contemporary small-scale artisanal mines in the Amazon are an ongoing source of mercury, which is bioaccumulating in food fish.

As the extent of damages from mining becomes more apparent, scientists, engineers, and regulators are investigating ways to mitigate the impacts of old mines and prevent current and future mines from developing similar problems. The most environmentally responsible gold mining companies are spending millions of dollars restoring the sites of closed mines and developing technologies to minimize the impacts of current mines. But many of these techniques are unproven in the long term or have already been proven ineffective, environmentalists warn.

A better solution, they say, is to site gold mines in only the driest and most seismically stable locations possible and to reduce gold consumption, because most—as much as 90% by some estimates—goes to nonessential applications such as jewelry. "There's no point in destroying communities, the environment, the water that we drink to mine a mineral that has no particular use other than to fulfill certain cultural fantasies," says Catherine Baldi, information coordinator for Project Underground, an extractive industry–focused environmental group based in Berkeley, California.

Clockwise from top left: Project Underground, Catherine Coumans, Mineral Policy Center, Project Underground



the Earth:

Gold Mining's Dirty Secret

Acid Mine Drainage: Eating Away at the Environment

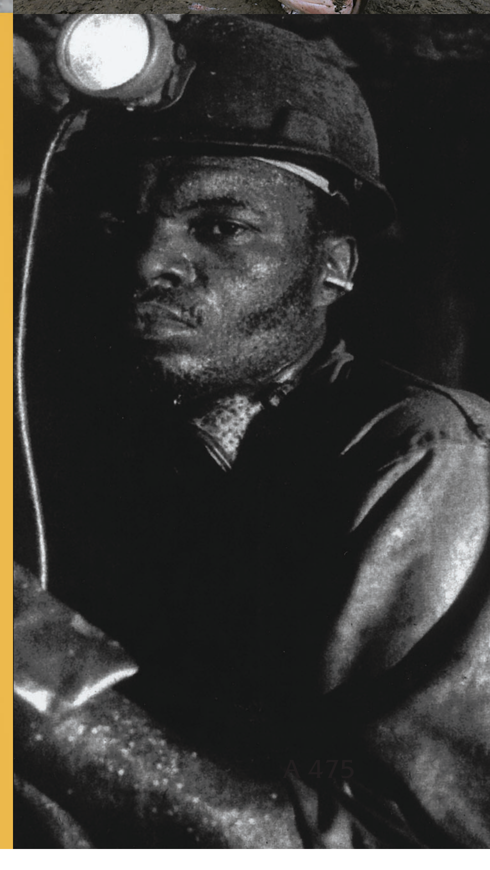
In the United States and Canada, gold mines—some more than 100 years old, some recently closed, and some active—are leaking acidic water, resulting in hundreds of millions of dollars in remediation costs. U.S. Environmental Protection Agency (EPA) officials estimate that 40% of western U.S. watersheds are affected by mining pollution. There are more than 25 mines, some of them active, on the U.S. Superfund list.

Of all the environmental hazards that gold mining presents, the mining industry and environmentalists agree that acid mine drainage (AMD) is by far the most serious. AMD is a process in which acidic water is produced from the combination of sulfide minerals (such as pyrite, marcasite, and chalcopyrite), water, air, and highly specialized bacteria.

Naturally occurring acid rock drainage has been around as long as sulfide minerals, air, and water have, and anthropogenic AMD dates back to at least the Middle Ages. But new techniques in mining in the last three decades have produced a virtual flood of acid water throughout the American West, Canada, and overseas, resulting in billions of dollars of expenses to mining companies and, more often, taxpayers.

Naturally occurring acid rock drainage can produce a trickle of acidic water that stains rock faces red. In fact, "red water" and the stains it leaves were one of the first signposts miners used to find mineral deposits. But mining can greatly accelerate the process. "When that rock was buried in the ground two, three, four, five hundred million years ago, whatever oxidation was going to occur in those systems has occurred or is occurring very slowly because it's all covered with water or isolated," Miller explains. "What [mining has] done is bring up that very reactive, potentially thermodynamically very unstable rock with respect to oxidation and put it near the surface."

According to the December 1994 U.S. Geological Survey (USGS) technical document



Acid Mine Drainage Prediction, once those sulfide materials are exposed to a steady supply of water and air, they begin producing sulfuric acid, and that in turn provides a medium in which thrive microbes that further oxidize the minerals, producing a self-perpetuating chain reaction. The resulting water can be so acidic that in underground mines it has dissolved iron tools, and in pit lakes it has killed migrating waterfowl that stopped for the night. (The most acid water in the world is found in underground caves at the Iron Mountain mines in northern California, a source for many metals, including gold. The pH there is -3.6, 10,000 times more acidic than battery acid.)

AMD seeps out of fields of tailings, piles of displaced surface matter ("overburden"), and piles of rock being slowly processed for gold removal. If left unchecked, it can contaminate groundwater and entire watersheds, contributing not just acidity but heavy metals—such as arsenic, lead, cadmium, mercury, zinc, iron, copper, aluminum, manganese, and chromium—which it releases from the ore it passes through.

At Spirit Mountain, Montana, AMD introduced lead, arsenic, and cadmium into the streams and aquifers that supply drinking water for about 1,000 people who live nearby. And the open pits themselves often fill with acidic water after mining operations cease.

Many mining pits intrude below the water table and so must be continually pumped dry. After the mine closes, the pumps are switched off, and the pit fills to become a small lake, in many cases an acidic one. As the level of the toxic water rises, it can begin to infiltrate into groundwater. Such is the case at the notorious Berkeley Pit, the legacy of a Butte, Montana, copper mine that used some of the same methods as gold mines. Today this pit threatens Butte's shallow drinking water wells.

Although a boom industry has emerged that specializes in AMD prevention and site remediation, acid drainage is difficult to prevent and even harder to stop once started. "There's not much you can do from a microbial standpoint to affect those processes," Moore says. "Once you get acid mine drainage, it's extremely difficult to stop it, and basically all you can do is treat it."

Typical treatments for already active AMD include adding lime to acidic water and intercepting and transporting leachate before it can enter ground or surface water. But these methods are expensive and, if AMD isn't halted, must be maintained indefinitely.

Preventing AMD in the first place is a better option, and good business too, says Keith Ferguson, vice president of sustainability for Canadian operations for the Vancouver-based Placer Dome mining company. That's why Placer Dome and other companies are researching ways to operate mines that do not produce acid. "There is a long-term liability and cost to [AMD]," he says. "That's not the way you want to operate mines."

Assuming that the rock bears sulfides, that means preventing either air or water from contacting the rock, says Debra Struhsacker, a geologist and environmental and government relations consultant to the mining industry. "If you point to old mines . . . many of them have acid rock drainage or acid mine drainage problems. But that's because those mines were built without the benefit of any kind of engineering design controls or environmental awareness about that problem," Struhsacker says. "Before you can get a permit at a mine today, you have to know whether the rocks you're exposing have the potential to be acid-generating. And if they do, you have to design the mine to address that issue."

From gold to red. Wastes from gold mining have leached acid and heavy metals into Fisher Creek, just outside Yellowstone National Park, turning its waters red.

In Nevada, where current and potential AMD mines abound, a wide variety of techniques are used to protect sulfide-bearing rock, says David Gaskin, chief of Nevada's Bureau of Mining Regulation and Reclamation. "It's a new science. There are a lot of traditional methods, but there are always new methods coming out," he says. Most systems are quite simple.

In a dry climate such as Nevada's, waste rock and tailings are covered with a layer of soil so thick that it can absorb all of the rain that is likely to fall in a given year. Sometimes a lower-permeability layer, such as clay, separates the rocks from the soil layer. On top, indigenous flora are planted. When rain falls in the wettest season, the soil absorbs the water before any can reach the sulfide rocks, and it holds the moisture until the dry season, when it evaporates.

In other situations, such as moderately wet climates, it is often more practical to deprive the rocks of oxygen by covering them in water, says Ferguson, which usually means planning in advance to build an additional pit in which to dump waste or to design a tailings impoundment that can contain waste rock as well. After the mine closes, the pit impoundment is flooded and then protected with a soil cover that lets rain in and keeps the rock saturated with water.

To further deprive the rock of oxygen, Placer Dome is experimenting with introducing biological agents in the wetted rock pile. Says Ferguson, "You then build up an organic layer where you get bacteria, like algae, and in that way you reduce oxygen right at the top layer of your tailing." To reduce the availability of sulfides to both water and air, other new techniques have been tried, such as autoclaving and encapsulating the rock in materials such as silica.

None of these techniques, however, are more than two decades old, and many may not work adequately or at all, Myers warns. "We have models that are being used that have never been properly validated. They've never been tested against a real-life situation."

Covering rocks and tailings, for example, may not prevent oxygen from reacting to sulfides in the rocks, he says. Substantial quantities of oxygen can be trapped in waste rock and tailings, and oxygenated water can infiltrate the area from other sources.

"No one will know [how effective these techniques are] until we start having some of these larger pits fill and see whether they go acidic or not," says Myers. "The mining industry and state regulators assume that it will all be submerged and will shut off the oxidation process. We say maybe, but if they're wrong we have a huge problem."

What's Wrong—and Right—with Cyanide

The term *cyanide* encompasses a variety of compounds produced by plants, soil bacteria, and invertebrate organisms, as well as commercially, that have a single carbon atom and a single nitrogen atom. According to the Mineral Policy Center, a mining environmentalist organization based in Washington, D.C., fatal human doses range from about 40 to 200 milligrams of pure cyanide or about a teaspoon of 2% cyanide solution. According to the World Health Organization, about 200 tons of sodium cyanide are produced per year, about 180 tons of which are used in gold mining.

Early methods of separating gold from unwanted materials relied on either flotation methods (in which a slurry of powdered ore,

Mineral Policy Center

Unhealthy alchemy. People are exposed to serious health hazards in the Amazon through the practices of panning with mercury (left) and torching mercury–gold amalgam to extract the gold (right).

David Cleary

water, and chemicals is injected with air bubbles, which forces gold flakes to the slurry's surface) or mercury amalgamation (in which raw materials are passed over sieves that are coated with mercury, which bonds to gold). But these methods aren't efficient enough to make extremely low gold content ore worth processing. Instead, large commercial mines use a "lixiviant" to dissolve minute particles of gold, freeing them from the ore to which they are bound. Cyanide has a virtual corner on the lixiviant market.

The "vat leach" technique of mixing cyanide and gold in containers has been in use since the nineteenth century. In vat leaching, the highest gold content ore is finely milled and mixed in vats with a combination of sodium cyanide and lime. This removes up to about 97% of the gold. Left over is a slurry of tailings that is stored in ponds where it eventually solidifies.

More recently, cyanide has been used with the technique of "heap leach" mining that supplements and sometimes replaces the vat leach technique. Proposed in 1969 by the U.S. Bureau of Mines and pioneered starting in 1973 by the Zortman and Landusky mines in the Little Rocky Mountains of Montana, cyanide heap leach processing is named for the vast heaps of ore it involves, which can cover tens of acres and reach several hundred feet high.

Ore that has too little gold content to justify vat processing is piled in heaps over which a solution of water and about 250–500 ppm sodium cyanide is sprayed. As the cyanide drips through the heap, it attaches to particles of gold and forms a water-soluble gold–cyanide compound from which the gold is later extracted. The gold-laden cyanide solution is collected at the bottom of the heap, which is usually lined with plastic over a barrier such as clay.

Typically, the heaps are built and processed in layers, or "lifts," with new layers added when lower layers have surrendered most of their gold. When the heap grows too tall to manage, typically about 300 feet high, a new heap is started. By the time the gold mine is ready to close, it can have excavated a pit as much as a mile across and half a mile deep, leaving behind acres of processed ore heaps and hundreds of millions of tons of waste rock, overburden, and tailings.

"[Cyanide is] so impressive, I can see why metallurgists don't even want to talk about anything else," Miller says. "It's so incredibly effective at pulling gold. There are no alternatives to cyanide that even really come close, except in specialized circumstances."

It is this very effectiveness, says Steve D'Esposito, president of the Mineral Policy Center, that has made mining companies complacent about finding a substitute for cyanide. "There are very few in industry who perceive a need for it," he says.

The other lixiviants for gold all have at least one fatal flaw, adds Miller. Thiourea was first mentioned as a lixiviant at least 60 years ago. But although it is less acutely toxic than cyanide, it is a suspected carcinogen. Like cyanide, it also dissolves heavy metals in addition to gold and so has the potential to cause some of the same damaging environmental effects as cyanide. Other possible replacements, such as thisulfate and halides (a group of chemically similar chlorides, bromides, and iodides) have similar disadvantages.

Mercury: The Old-Fashioned Approach

Although not feasible for use with low gold content ore, perhaps even more effective than cyanide is the oldest chemical method for separating minute particles of gold from surrounding materials: amalgamation with mercury, which was used in ancient Rome and in the United States during the California gold rush, and is still used today at artisanal mines deep in the Amazon jungles. Typically, gravel and mud are combined with liquid mercury, which binds to gold particles in the mix.

But mining with mercury invariably introduces mercury to the environment. "Mercury is a huge issue these days in Southern California, environmentally, and the reason it's out there is mining, both mercury mining and gold mining," says Charles Alpers, a research chemist with the USGS. In just over three decades ending in 1884, gold mines in California's Sierra Nevada range introduced 3–8 million pounds of mercury to the environment.

Today hundreds of thousands of pounds of mercury remain at each of the hundreds of gold mining sites in the area, according to the USGS report *Mercury Bioaccumulation in Fish in a Region Affected by Historic Gold Mining: The South Yuba River, Deer Creek, and Bear River Watersheds, California, 1999*. This mercury converts into the more dangerous methylmercury form and bioaccumulates in invertebrates, amphibians, and fish, resulting in severe restrictions in the recommended safe consumption levels of game fish from the area. "We found more than one part per million in some of the bass in lakes on the Bear River," Alpers says. "The average is around point-nine or point-nine-five for bass in those lakes. And some of the trout were over point-three, which is the new EPA guideline for mercury in [food] fish."

More than a century after mercury-based gold mining effectively ended in California, the environmental and financial effects continue to impact hundreds of miles of U.S. river systems. The Amazon's 25-year-long gold rush may cause similar effects for years to come.

In the late 1970s increasing gold prices and the discovery of alluvial gold deposits along scattered river systems sent small bands of miners called *garimpos* prospecting deep into the Amazon jungle, says David Cleary, who is the Amazon program manager of the Brazil Division of The Nature Conservancy. Like the California miners of the nineteenth century, who often poured hundreds of pounds of mercury into troughs using a 76-pound flask, the Amazon miners use mercury-coated sluices to glean gold from river deposits. "The rock comes out of the sluice boxes as mercury–gold paste," Cleary explains, "and the miners at the point of mining generally just put it under a blowtorch and boil the mercury off it. Then it goes into a trading chain, and at each stage on the trading chain the traders will blast it again under a blowtorch to get the residual mercury out."

According to Roberta White, a professor of neurology at Boston University Medical Center, this mercury has entered the food chain and has led to measurable mercury poisoning of indigenous populations who eat fish from these rivers. And because the miners both eat fish and breathe fumes, they are doubly afflicted. "They often had straight-out mercury exposure as well as methylmercury exposure, and some of them were quite impaired on neuropsychological tests," White explains. As in California 120 years ago, since the late 1970s vast quantities of mercury—at least 2,000 metric tons by one estimate—have been added to regional waterways in Brazil and neighboring countries, according to an article in the 1 May 1998 issue of *Environmental Research*.

When metal mercury is methylated in the environment into methylmercury—typically by bacteria—it builds up in the food chain. At low levels methylmercury can cause subtle subclinical nervous system dysfunction such as that noted by White, and at high levels it has been linked to tremors, paralysis, anemia, bone deformities, and death. "I think that the whole area is contaminated, with more effects than we realized," White says.

Research published by White and colleagues in the July 1999 issue of *EHP* has demonstrated that mercury poisoning traceable to the Brazilian gold mining boom has decreased the performance of indigenous children on a battery of cognitive tests of visual spatial function and memory. "What this suggests to us is that the central nervous system has been affected by the methylmercury," White says.

View to a kill. An aerial view of the environmental damage wreaked by the Summitville mine in Colorado.

Mineral Policy Center

Tailings Spills Take a Toll

"The problem with cyanide is the scale of mining that it [allows]," says Tom Myers, a hydrologist and director of Great Basin Mine Watch, a Nevada environmental group. Cyanide, he says, has allowed heap leaching, and heap leaching lets mines profitably work deposits that otherwise would stay in the ground. That very scale magnifies the potential environmental impacts that have long been associated with mining. The 1 billion tons of tailings produced in the United States each year are contaminated with cyanide and heavy metals and must be disposed of or contained. And, Miller says, tailings impoundments often leak or fail completely.

The techniques used to manage tailings are identical for gold mining and other metals, such as copper, but the application of these techniques to gold mining is relatively new. As a result, there haven't been as many opportunities for toxic pits to develop and tailings dams to fail. But over time, if unchecked—and checking may not be possible—the outcomes will be the same for gold mines as for other, older mines.

Because these large-scale mining operations are fewer than three decades old, the technologies for lining tailings impoundments are also new—in fact, about half that age—and so unproven, says Dirk van Zyl, a professor of mining engineering and director of the Mining Life-Cycle Center at the University of Nevada's Mackay School of Mines. Unlike heaps, which must be lined to collect cyanide leaching solution, some tailings impoundments are unlined, and others are lined with just a layer of clay (in the United States and Canada, requirements for liners depend on state and provincial regulations).

But most new tailings impoundments, Van Zyl says, use composite liners, which are also used for heaps. The composite's base is usually clay, and above that is a plastic layer, typically polyethylene or polyvinyl chloride. The plastic sheets are rolled and then welded together with heat, the extrusion of molten polyethylene, or chemical bonding. But if during installation the seams aren't connected properly or the sheets are somehow perforated, the liner will leak. "You are really very dependent on the integrity of the synthetic layer," Van Zyl says. "There is always speculation about how long these materials will last."

According to geology professor Johnnie N. Moore of the University of Montana at Missoula, the liners won't last long enough. "People say they're not going to leak," he argues. "Yes, they're not going to leak for twenty years or maybe thirty years, but all of the liner materials that are produced are not going to last for a hundred years, and they're probably not going to last for fifty, and they're *certainly* not going to last for five hundred years."

Cyanide is the most likely substance to leak from gold mining tailings. In spite of cyanide's extreme toxicity, the environmental impacts of noncatastrophic releases of cyanide from impoundments are mitigated because cyanide breaks down quickly in sunlight. But sometimes free cyanide (cyanide ions and hydrogen cyanide) breaks down slowly—for example in water that is ice-covered and so protected from direct sun. More often, it can break down into less toxic but longer-lasting forms, such as cyanate and cyanogen, according to *Cyanide Uncertainties*, a 1998 issue paper written for the Mineral Policy Center by geochemical and hydrogeological consultant Robert Moran. Free cyanide will quickly kill aquatic animals, and although the toxicity of individual cyanide complexes and their propensity to bioaccumulate in animals is not well understood, fish are known to be more sensitive to cyanide than mammals.

Cyanide is highly reactive with many heavy metals, and during either heap leaching or vat leaching can form a variety of metal–cyanide complexes. "When you run cyanide through a heap, it leaches not only gold and silver," says Myers, "it also leaches arsenic, mercury, selenium, and certain other heavy metals." Although cyanide doesn't react directly with many of these metals, it does break down the sulfides to which they are bound, releasing them. As a result, when tailings containments leak, these metals often enter ground or surface water. Increases in mercury levels in water systems, Miller says, have been linked to tailings leaks.

Arsenic is often found in runoff from gold mines, says Kirk Nordstrom, a hydrogeologist with the USGS. Hydrothermal gold deposits, thought to be formed when hot water moving through the earth's crust dissolves metals and is carried closer to the surface, almost always will have significant amounts of arsenic associated with them, he says. Although the cyanide doesn't react strongly with the arsenic itself, he explains, it does attack the metals to which the arsenic is bound—the sulfides and pyrite. As a result, Nordstrom says, "the arsenic that is in there is going to mobilize faster."

Although tailings ponds eventually dry out to become tailings fields, they continue to pose environmental hazards, Miller says. Rain passing through the materials can mix with metal–cyanide complexes, and leak out of impoundments and into ground or surface water. Even if tailings stay dry, he says, they can generate potentially hazardous dust. The milling step of the vat leaching process generates fine particles, and the lime that is mixed with cyanide prevents small particles from binding together as large particles. The smallest of these particles—smaller than 1–5 micrometers across—can lodge deep in the lungs, says Miller, and even normally inert substances such as silica are, at such small sizes, suspected to be biologic irritants associated with fibrosis and lung cancer.

Some of the metals found in these dusts, Miller says, include selenium, antimony, and copper, as well as such known and suspected carcinogens as arsenic, cadmium, and chromium. Placer Dome's strategy for preventing these sources of toxic dust, Ferguson says, is to use earthen covers to control water content in the tailings fields and to recreate the area's original landscape and replant native fauna. But an added hazard, says Van Zyl, is that these released metals will be absorbed by plants that are eaten by either humans or animals, starting a process of bioaccumulation in the food chain.

The homogenous nature of these tailings fields, Miller says, assures that they will remain an "unlimited reservoir" of dust for years to come. If the fields were a mixture of fine and coarse materials, he says, the fine materials would soon disperse, and coarser materials would then protect the layers below them from further erosion. But because the materials are uniformly fine and often elevated more than 50 meters above surrounding terrain, they are an ongoing source of dust in Nevada. "The good news is that if you get lost out there within thirty miles, you can find out where you are just by seeing the white cloud of dust coming off the tailings facility," Miller says.

In sparsely populated Nevada, relatively few people are likely to come in contact with these dusts, Miller says, but in other areas around the world the risks are far greater. "In South Africa, for every ounce of gold produced they have ten times more workers than in the United States," he says. These workers typically live with their families in densely packed communities surrounding the mine fields, exposing adults and children alike to pollutants from these facilities.

Mineral Policy Center

Split earth. At the Omai Mine in Guyana, 3.4 million cubic meters of cyanide-rich effluent was released when a tailings dam failed.

When impoundment dams fail, spectacular disasters can follow. In the last decade, accidental tailings releases in several countries around the world have contaminated hundreds of miles of rivers, killing thousands of tons of fish and resulting in hundreds of millions of dollars of cleanup costs.

Tailings spills—from gold mines and other types of mines that use the same impoundment methods—are not unusual, either. For example, according to the 1997 EPA report *Risks Posed by Bevill Wastes*, cyanide solution leaking from the Summitville, Colorado, gold mine—a Superfund site—contaminated the Alamosa River and penetrated as deep as 10 feet into the soil. The EPA estimates cleanup of the site would cost about $150 million. In 1998 between 6 and 7 tons of cyanide-tainted tailings leaked from a South Dakota gold mine into the Black Hills' Whitewood Creek, damaging the stream for years to come, says Moran. The 1990s saw equally damaging releases in Montana, Nevada, and South Carolina.

But although leaks can have significant environmental impacts, more damaging are the massive spills that result when a tailings impoundment collapses. Unlike in the United States—which, according to Van Zyl, requires cyanide-containing tailings impoundments to be lined and built of coarse materials such as waste rock—tailings impoundments overseas are made by bulldozing the first batch of tailings into a dam. After the dam dries, it is used to contain more wet tailings. As the facility grows, the dam is continuously layered with additional tailings, using a variety of techniques depending on local climate, seismic stability, and regional regulations.

But no matter which method is used, Moore says, a wet tailings dam can collapse as quickly as a sand castle. "As long as it's dry and you've got enough of it, it's a pretty good dam," he says. "But if you don't keep it that way, they're very prone to failure." That's why, Miller says, the first requirement for opening a mine that is ultimately going to have a higher probability of closing without environmental problems is to find a place that has less than 10 inches of precipitation per year and a hot climate.

According to Moore, tailings dams break regularly. "When they break," he says, "it's disastrous because the tailings spread over a wide area." In June 2001, for example, a tailings dam in Brazil fractured, killing at least five people and dumping mine waste into the Green River. A 1995 dam break in Guyana sent more than 2.5 billion liters of cyanide-tainted water into the Essequibo River, the country's primary waterway. In March of 1996, a badly sealed tunnel in a tailings impoundment gave way in the Philippines, completely filling a 26-kilometer-long river with 4 million tons of tailings containing copper, lead, mercury, cadmium, and other heavy metals. And in Spain on 25 April 1998, a tailings dam failed at a lead–zinc mine near Seville, releasing 6.8 cubic meters of acidic and heavy metal–laden tailings into the Agrio River, a tributary of the Guadiamar River. The slurry also flooded thousands of hectares of farmland.

More widely reported was a tailings dam failure at a Romanian gold mine on 30 January 2000. The tailings dam at Baia Mare ruptured, releasing an estimated 100,000 cubic meters of cyanide-tainted liquid into the watershed that feeds the Danube River. The material deposited heavy metals including copper, lead, and zinc, and killed virtually all aquatic life (while threatening fish-eating animals such as otters and eagles) for the 250 miles of the river system that passes through Hungary and Yugoslavia before emptying into the Black Sea. According to Hungary's Ministry of Environment, drinking water for 2 million people was affected, and long-term problems may exist because of metals released in the sediments.

When Waste Meets Water

In especially wet climates, companies sometimes forgo tailings storage entirely. Instead, they dispose of their tailings directly in rivers and oceans. Although the original method of tailings disposal in North America was to pour the waste directly into rivers, by the turn of the nineteenth century that practice was severely restricted in the United States and is now outlawed in the United States and Canada. Some North American companies, however, do continue to employ "submarine tailings disposal," or STD (dumping into oceans), and "riverine tailings disposal" (dumping into rivers) in Third World countries such as Papua New Guinea, Indonesia, and the Philippines.

In the lush hills and mountains of Papua New Guinea, several mining companies dump mining wastes directly into rivers and oceans. Placer Dome operates gold mines that use both techniques. "It's an area of extremely high rainfall. I think it's approximately four meters a year," says Ferguson. "It's extremely rugged terrain with landforms that tend to be rather unstable. And it's also in a high seismic area with very high earthquake potential. So you put all those together, and certainly a [tailings] dam poses its own risk."

It is because of these physical characteristics, Ferguson says, that it is environmentally safer to use rivers and oceans to continuously remove tailings and waste rock from certain mining operations than it is to take the chance of a catastrophic containment failure. At Placer Dome's Misima mine in Papua New Guinea, the company sends tailings through a pipe that leads to the edge of the ocean shelf. From there, Ferguson says, the tailings travel in a cohesive stream, like toothpaste squirted from a tube, into a deep ocean trench 1,000 meters below the surface. To ensure that STD doesn't harm sensitive biota, the company monitors areas such as nearby coral reefs; according to Ferguson, the waste rock and tailings travel well below the coral without affecting it.

Environmentalists warn, however, that STD is fraught with potential environmental impacts even when the system works perfectly, which they say is rare at best. Sometimes mechanical devices fail. In July of 1997, for example, the Misima mine's pipe ruptured at 55 meters below the sea, shallow enough, says Catherine Coumans, research coordinator for the environmental advocacy group MiningWatch Canada, to still threaten sensitive ecosystems.

More mine waste. Cyanide-tainted effluent from the Baia Mare gold mine in Romania poisoned fish in the Danube River.

"I haven't been able to find a single [STD system] where the pipe hasn't broken, either on land or in the sea," she says. "That's a real weak point with submarine disposal. These pipes are constantly corroding and breaking." Such spills have been linked to sea life kills and bioaccumulation of toxicants in food fish harvested by local people, adds Baldi.

Almost as troubling, Coumans says, are the impacts of submarine disposal even when the systems work as intended. At Misima, the level of cyanide in the tailings is so high, even after a 7:1 dilution with seawater in a shoreline mixing tank, that there needs to be a 1,200 × 530 meter mixing zone in the sea to allow water to meet Papua New Guinean standards for cyanide in seawater. After the cyanide-laden tailings leave the underwater pipe at the Misima mine, she says, rather than travel as a coherent mass, "some of the fine particles actually shear off from the main cur-

A poisoned river runs through it. Tailings from the Porgera gold mine in Papua New Guinea meet the waters from a clean tributary about 30 kilometers downriver from the mine (left). Nearby, children play in the tailings, which were found to contain unhealthy levels of lead, arsenic, cadmium, and other toxic metals (right).

Top to bottom: Mineral Policy Center, Catherine Coumans rent at various depths," something she says commonly occurs in STD systems. Once separated, the toxic particles can become trapped between layers of water of contrasting temperatures and densities, and these turbidity plumes have been known to be carried hundreds of kilometers away from their intended resting place.

Even those tailings that do settle at their target depth may not stay put. "If there's an upwelling or an earthquake, those tailings are going to get remobilized, they're going to go wherever they go, and no one will be able to do anything about it," Coumans says. And even if the hundreds of millions of tons of waste material doesn't stray, she says it will at the least blanket tens to hundreds of square kilometers of ocean floor, smothering all life below it and providing a continuous source of metal contamination up the food chain.

Disposing of mining wastes directly into rivers presents, if anything, more serious hazards than STD, environmentalists say. "By dumping toxic tailings that contain heavy metals into fisheries, it ends up killing off fisheries and effectively making communities around it sick, because people eat the fish that do survive, and the fish will collect and concentrate heavy metals," Baldi says. "We have freshwater rivers where tailings are being dumped, and communities are drinking water out of it so they're getting directly exposed to the [toxicants] in the tailings."

According to Ferguson, riverine disposal, when executed correctly, is environmentally benign. The trick, he says, is to employ large, turbulent rivers that are capable of transporting significant quantities of solids. It's also important that the mine be far enough upstream from inhabited areas to allow time for the waste materials to disperse.

Such is the case, he says, with Placer Dome's Porgera gold mine near the Fly River system in the Papua New Guinea highlands. Placer Dome and the Papua New Guinean government—which owns a share of the Porgera and Misima mines—consider the first 160 kilometers of the river to be a mixing zone in which mining wastes become diluted to safe concentrations. The company conducts an extensive environmental monitoring program of the region in which the mine operates, Ferguson says, including sampling stations 40 and 160 kilometers downstream from the mine. By the 160-kilometer point, the water meets Papua New Guinean regulatory requirements for heavy metal content.

Environmentalists, however, contend that riverine disposal is never harmless. Coumans cites the Fly River as proof that no river is big enough, sufficiently fast flowing year-round, or far enough from people and sensitive biosystems to safely transport and disperse millions of tons of tainted wastes. A stretch of 160 kilometers, she says, is far too long a stretch of water, accessed by far too many people and animals, to be allowed to exceed heavy metal level standards.

The result, Coumans says, is deposition of tailings sediments and heavy metals in the river bed and on its banks hundreds of kilometers downstream (where the river slows down), contamination of food fish supplies, as well as disturbing anecdotal reports such as livestock dying after drinking river water and human health problems such as a mysterious hemorrhagic disease of unknown origin.

She adds that the point at which the tailings enter the river system presents its own serious human health hazards. When the disposal pipe breaks, as it frequently does, local people pan for gold in the tailings as they spill out of the crack. "That location is absolutely swarming with children and with adults who are actually panning the tailings, panning the waste rock, for gold," Coumans says. "Their bodies are just powdered with these tailings."

Gold Futures

As long as people demand gold, mining companies are going to mine gold, says Baldi. The sad irony, she says, is that virtually all of the gold mined is used for frivolous applications. "People need to figure out that there is no point in mining [gold] anymore, that whatever we have in reserve can be used to fulfill industrial production," she says.

According to David Chambers, a geophysicist and executive director of the Bozeman, Montana–based Center for Science in Public Participation, all of the gold required by industry could be supplied by the 10% of total annual production that recycling generates (for example, gold from industrial applications and old jewelry). "If you look at the production figures—how much gold is produced in the world every year—and then you look at how much goes to jewelry, there is almost a one-to-one correlation," he explains.

A mantra of the mining industry is that if you want gold, you have to mine where the gold is, which may not be the best place to open a mine. As the demand for gold increases, so will the likelihood of mining companies opening facilities that are either in increasingly remote, pristine locations or that process decreasingly rich ore. "If gold goes to four hundred [per troy ounce], all hell's going to break loose around here," says Myers. "There are an awful lot of deposits around here that are profitable at four hundred dollar gold."

And that, says Moore, is bad news for both the environment and taxpayers. "I don't know of any mine anywhere that doesn't have water quality problems," he says. "And I don't know of any closed mines anywhere, even new ones, that don't have tremendous long-term problems that are going to saddle the taxpayers with cleanup and monitoring and remediation methods for perpetuity. That's not a very good industry, in my view—one that you have to pay for the product forever."

Scott Fields

Mining and Disease

Another impact of gold mining on the indigenous peoples in the Amazon is the introduction of diseases such as new strains of malaria, says Stephan Schwartzman, director of international programs for Environmental Defense. "The great effects and the tragedy of uncontrolled contact with outsiders—as typically occurs in gold rush situations—is that [indigenous peoples] get diseases to which they have no resistance," he says, because they were previously isolated. Thousands of Yanomami Indians died in the Brazilian gold rush. Some tribes lost 80% of their populations to diseases within five years of their first contact with gold miners in 1968.

The disease that has had the most lasting impact, says Cleary, is malaria. The gold rush produced a three-pronged attack. It introduced methylmercury to the local diets, which, according to a presentation given by Ellen Silbergeld of the University of Maryland School of Medicine at the 1998 annual meeting of the Society of Toxicology, may lower immunity to malaria.

It also pummeled rivers with water cannons, dredges, and other mining equipment, creating still pools of water that serve as breeding grounds for malaria-carrying mosquitoes. "What [mining] does to the rivers is disastrous. It looks like a moonscape. You have pits of standing stagnant dirty water on all sides," Schwartzman says. "The natural flow of the river is completely disrupted, as are all the streams that feed into it."

Finally, miners from other areas imported new strains of the disease. "The mines open up, the miners go in," says David Cleary, the Amazon program manager of the Brazil Division of The Nature Conservancy, "and then you have devastating malaria epidemics." **–Scott Fields**